

Nuclear Energy University Programs

Advanced Reactor Concepts (ARC-1)

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August 10, 2011



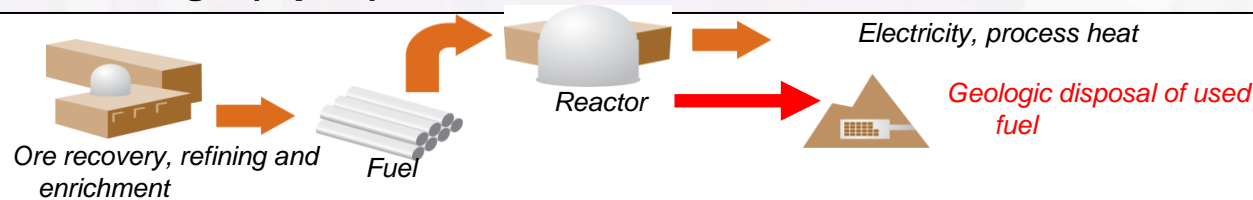


Advanced Reactor Concept Development – Technical Work Scope

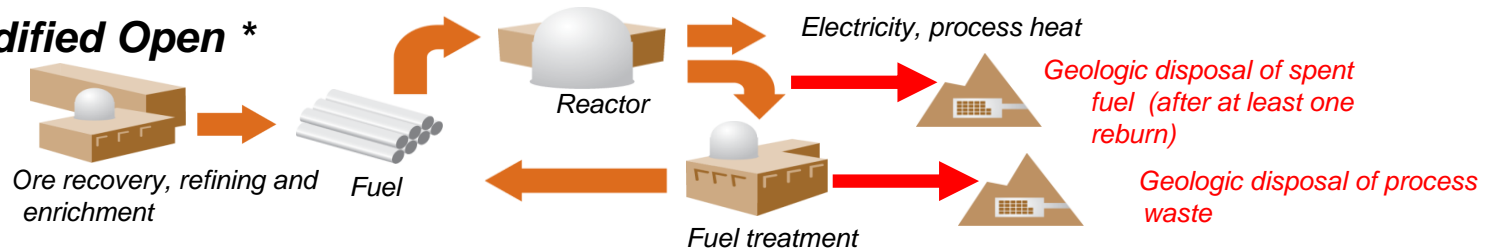
- ARC-1 - Development of new reactor concepts that use advanced technologies or innovative engineering is sought.
- The goals of the advanced reactor system should be to provide electricity at the same cost or lower than light water reactors with improved safety and system performance.
- This category could include either radically new systems or the incorporation of advanced systems and components into existing reactor concepts.
- Components within this scope include, but are not limited to innovative designs for containment, seismic, fuel handling, pumps, safety systems, and instrumentation for both operations and maintenance.
- The scope of the proposed project should include a thorough viability and applicability assessment of the proposed reactor system, advanced systems and/or components, a detailed technology gap analysis, and a comprehensive technology development roadmap.

Potential Fuel Cycle Options - Background

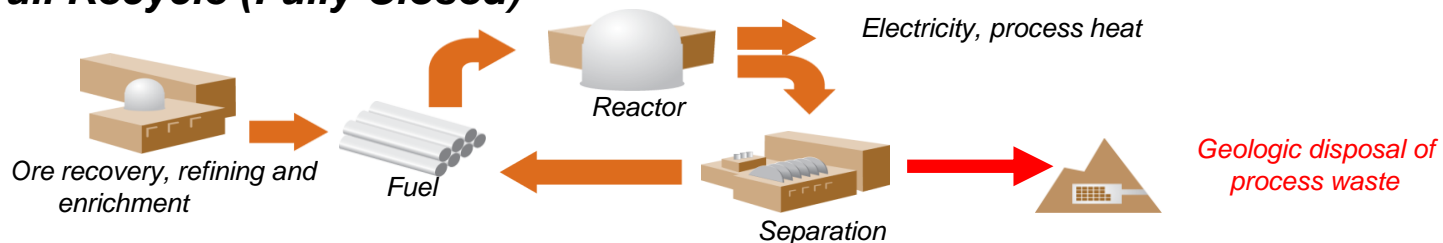
Once-Through (Open)



Modified Open *



Full Recycle (Fully Closed) *



*A specific fuel cycle strategy may include more than one fuel design, reactor design, or fuel treatment process.

Transmutation Nuclear Technology needed for latter two fuel cycle options ³



Advanced Reactor Concepts Grand Challenges

The Advanced Reactor Concepts (ARC) mission is to research and develop advanced technologies to significantly improve the efficiency and safety performance of advanced reactor systems

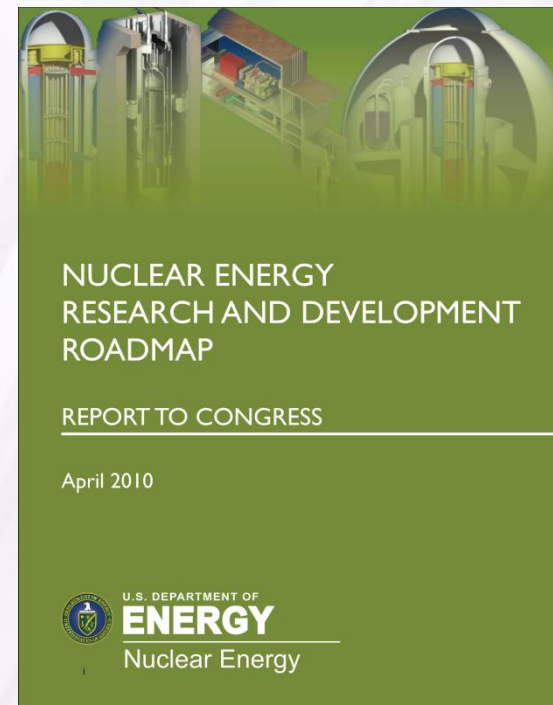
Three grand challenges have been identified:

- Develop advanced reactor options that meet a broad range of fuel cycle strategies ranging from deep burn actinide consumption to extended uranium utilization
- Develop high performance advanced reactor options with usable energy products – comparable to LWR generation costs
- Demonstrate prevention of radiation release to public for all events – normal operation, accidents, or malevolent acts
- In FY2011 – Advanced Very High Temperature Thermal Spectrum Reactors were added to ARC program.

Advanced Reactor Concepts Objective(s) and Needs



- *ARC Objective - Develop advanced reactor technology solutions to allow commercial deployment by 2050 timeframe*
- *Supports Nuclear Energy R&D Roadmap Objectives (2 & 3)*
 - *(2) Develop improvements in the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals*
 - *(3) Develop sustainable nuclear fuel cycles*
 - *"The overall goal is to have demonstrated the technologies necessary to allow commercial deployment of solution(s) for the sustainable management of used nuclear fuel that is safe, economic, and secure and widely acceptable to American society by 2050."*
- *Advanced reactor systems and components are part of the technologies being investigated under the ARC program to develop viable AFR technology solutions for commercial deployment by 2050.*
- *ARC Program is investigating both fast and thermal spectrum systems.*





Overview of Advanced Reactor R&D

- **For future advanced reactor technology deployment, a key research focus is high performance**
 - Improved design approach (e.g., compact configuration) to reduce cost and improve performance
 - Advanced technologies (e.g., materials, energy conversion)
 - Advanced simulation for optimized design
- **For the closed (or modified) fuel cycle, must develop and demonstrate the advanced fast reactor system**
 - Fast spectrum needed for final transmutation system
 - Sodium coolant technology chosen if near-term application
- **Major technology R&D areas include:**
 - Advanced modeling and simulation (*separate talk*)
 - Advanced materials (*separate talk*)
 - Advanced energy conversion technology (*separate talk*)
 - Nuclear data
 - Safety Research
 - Reliability and Monitoring technology (e.g., under-sodium viewing)
 - Fast and Thermal Spectrum Concepts R&D
 - International Collaborations



Advanced Reactor Concepts R&D Structure

Programmatic Lead (NTD) for ARC R&D area – Dr. Robert Hill (ANL)

Technical leads coordinate set of multi-Lab work packages

- *Program Lead and International Collaborations (Hill-ANL) w/LLNL (on LFR)*
- *Fast Spectrum Systems R&D (Grandy-ANL) w/INL*
- *Safety Research (and Regulatory Crosscut) (Sofu-ANL)*
 - *Regulatory Scope (LaChance-SNL) w/INL, LBNL, BNL, ORNL*
- *Thermal Spectrum Systems R&D (Holcomb-ORNL) w/INL*
- *Energy Conversion (Rochau-SNL) w/ANL*
- *Reliability and Monitoring Technology (Grandy-ANL) w/PNNL*
- *Advanced Materials (Sham-ORNL) w/ANL&INL*
- *Modeling and Simulation (Bradley/Khalil-ANL)*
- *Nuclear Data work funded by Fuel Cycle R&D, not Gen-IV*

ARC Reactor Program – Overview (1/2)



- To address the “Grand Challenge”, we have been performing R&D at the Fuel Cycle Level to explore innovations
- Under the Gen-IV funding in FY2010, Dr. Robert Hill (ANL) sent out a request to the DOE labs for transformative reactor concepts for the nuclear energy mission
- He received 19 ideas for transformative nuclear systems/concepts
- These concepts were reviewed and evaluated by an expert panel
- More detailed discussion later

Concept of Pebble-Bed Fluoride Salt-Cooled HTR

Development of Performance-Based Regulatory Method

Fast-Flux Modular Reactor

Fast-Spectrum Molten Salt Reactor

Heat Pipe Fast Reactor for Burning and Power

High Flux, Dedicated Transmuter for Am and Cm

Integrated Metallic Fuel Reactor

Laser Inertial Fusion-Fission Transmutation

Lead-Cooled Transformational Reactor

Lead-Cooled Transmutation Reactor

Liquid-Salt Cooled Fast Reactor

Nano-Fluid Nuclear Reactor

Reduced Moderated Boiling Water Reactor

Spent Fuel Disposal using Small D-T Fusion Driver

Subcritical Minor Actinide Transmutation

Supercritical CO2 Fast Reactor

Thorium Based Sodium-Cooled Fast Reactor

Thorium Fuel Cycle: Proliferation Benefits

Ultra-Fast Spectrum Transmutation Reactor

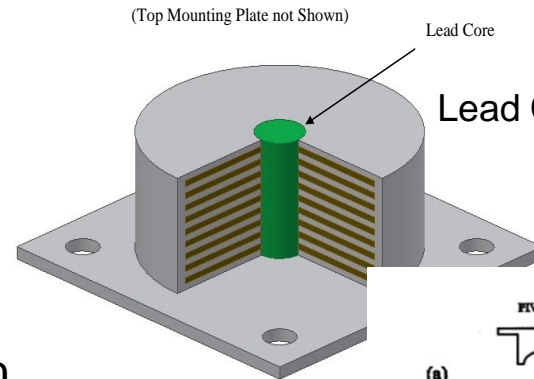


ARC Reactor Program – Overview (2/2)

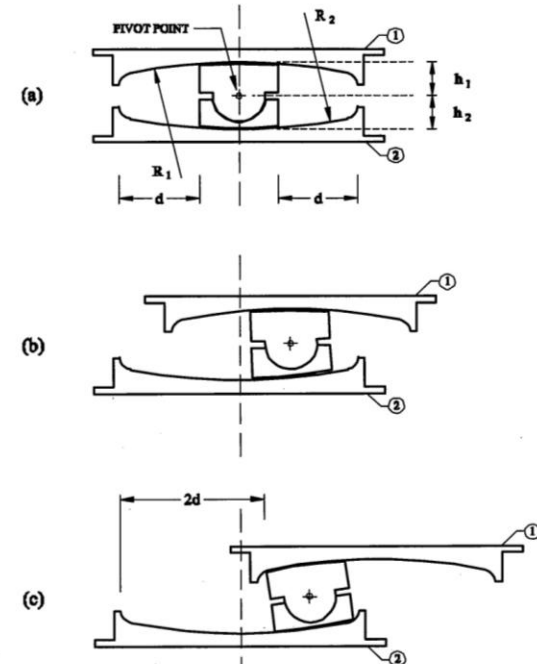
- To address the “Grand Challenge”, we have also been performing R&D at the reactor systems and components level to explore innovations:
 - Advanced materials for reactor structures – e.g., we have chosen (2) advanced materials for structures and (2) for heat transfer components – this is a crosscutting area
 - Engineered coolants – e.g., using nano-particles to adjust thermo-physical properties of a chosen coolant to increase coolant and system performance
 - Advanced fuel handling systems – e.g., compact fuel handling systems – reduces space requirements (includes safeguards)
 - Advanced controls and instrumentation
 - Seismic Isolation Technology
 - Advanced Modeling and Simulation
 - Improved Nuclear Data
 - Compact heat exchanger technology – e.g., printed circuit heat exchanger technology
 - Advanced Energy Conversion
 - Reliability, Maintainability and Inspectability technology – e.g., ultrasonic transducer technology to “look” through non-transparent coolants for in-service inspection

Seismic Isolation Technology

- Although seismic isolation technologies are established, they have not been deployed in any current reactor plants within the U.S.
- May be required for reactors deployed in seismically active areas
- Small Modular Reactors may need seismic isolation systems to be a “standardized” SMR and deployable system
- Containment location or airplane shield may pose challenges for this technology
- Accommodating relative pipe movement across the seismic gap may also be a challenge



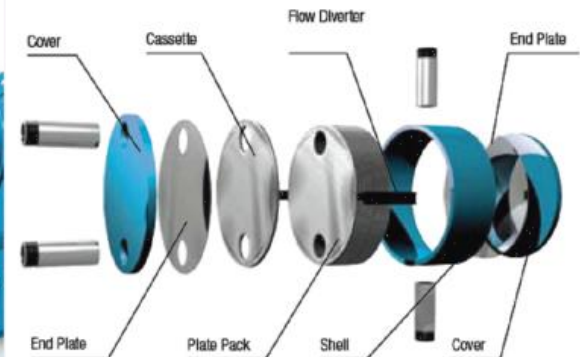
Lead Core Elastomeric Bearing



Multiple Friction Pendulum System

Compact Heat Exchanger Technology

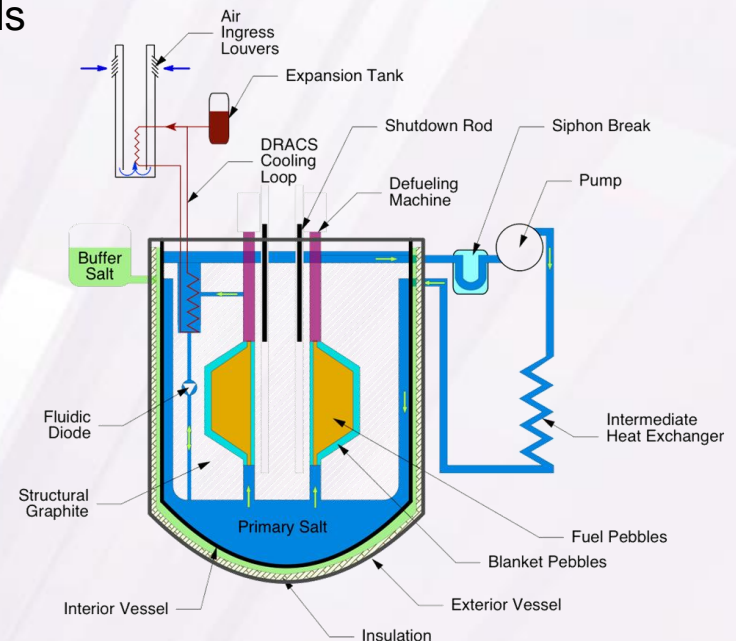
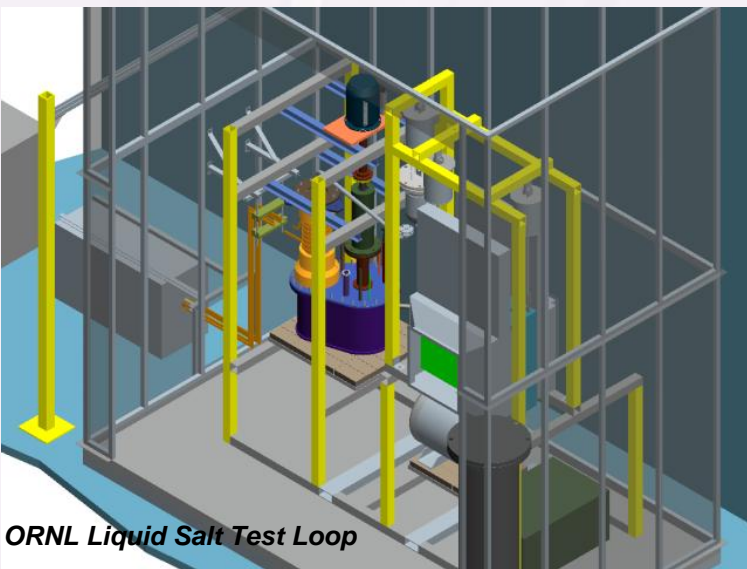
- Compact heat exchanger technology can reduce commodities and footprint reduction
- Current State of the Art is enhanced tube and shell heat exchanger technology
- For example, in our liquid metal reactor studies
 - A hybrid HX configuration suited for the Na-to-CO₂ heat exchanger is the this heat exchanger with larger Formed Plate Heat Exchanger (FPHE) channels on Na side and smaller Printed Circuit Heat ExchangerTM (PCHETM) channels on the CO₂ side
 - Plate and Shell Heat Exchangers
- Heat Exchangers that can accommodate high ΔP



ARC Program R&D Scope

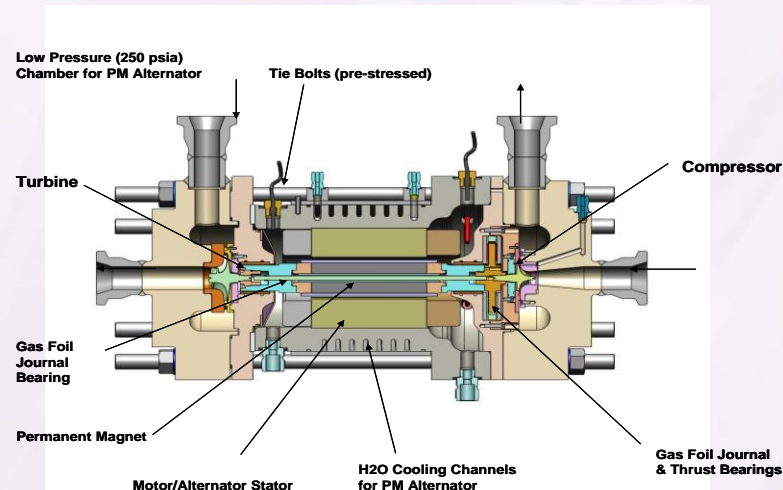


- Fluoride-Cooled High Temperature Reactor (FHR) Development
 - Provide high-temperature heat for electricity and process heat applications using low pressure primary systems with unique safety characteristics (large thermal margins of $>500^{\circ}\text{C}$ to fuel damage during transients and accidents)
- R&D of FHR concepts and supporting technologies
 - Develop and validate integrated structural, thermal, and hydraulic models for evaluating core design options
 - Investigate fluoride salt properties, heat transfer capabilities, and chemical interactions (corrosion control) with structural materials
 - Assess refueling strategies
 - Identify technology gaps and future R&D needs



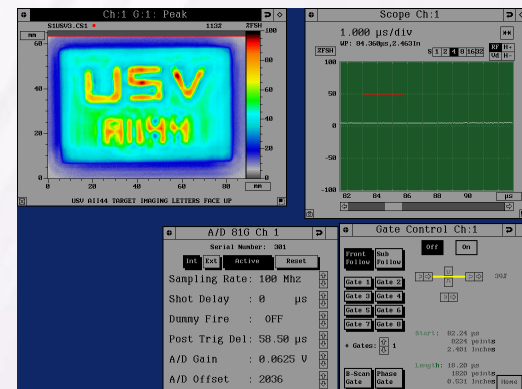
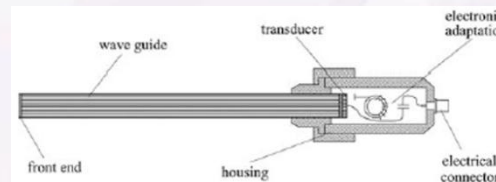
Advanced Energy Conversion Technology Development

- Supercritical CO₂ Brayton Cycle R&D, testing, and demonstration
 - applicable to multiple advanced reactor concepts (as well as existing fossil and nuclear commercial power generating systems)
 - shows significant potential for energy conversion systems with greater efficiency at lower operating temperatures
 - can be fabricated from standard commercial materials
 - compact design supports modularity and cost reductions
- Continuing tests using .5MW_e system; constructing 1MW_e system; and designing 10MW_e power system
- Investigating alternative supercritical working fluids and mixtures



Reactor Systems for Reliability, Maintainability, and Inspectability

- Advanced In-service inspection technology for reactor permanent structures
- In-situ repair technology for reactor plant systems and components
- ISI&R technology may be coolant-type specific
 - Water based, liquid metal based, salt based, etc
- Current focus is on ultrasonic technology for under-sodium viewing





Reactor Program - Safety Research

- Development of enhanced safety technologies for accident prevention and mitigation
 - Perform integrated analysis of design concepts for safety assessment
 - Develop advanced modeling and analysis methods for performance verification
 - Perform model validation
 - Participation in IAEA benchmark activities for MONJU and PHENIX reactors
 - Preparation of benchmark specification for an EBR-II passive safety test
- Preserve and nurture the domestic knowledge base and U.S. professional expertise to facilitate science-based R&D
 - Preserve available safety testing data for future model validation tasks
 - Focus on database archiving of safety-related experimental data from EBR-II, FFTF, and TREAT; use in benchmark validation analyses
- Propose licensing criteria and science-based approach for demonstration of regulatory compliance
 - Gap assessments for safety analysis models/codes for licensing and fuel behavior
 - Quantify safety margins and uncertainties for licensing applications



Diverse international collaboration avenues continue:

- Bilateral agreements with France and Japan on specific items
 - Participation in MONJU restart (validation data)
- Trilateral MOU signed with France (CEA) and Japan (JAEA) for SFR development
- Additional collaboration on SFR and LFR technology development through the Generation-IV International Forum
 - Active role in five multi-lateral Technical Projects and two Steering Committees
- Bilateral working group on fast reactor technology with China
 - Initial focus on transfer and training on fast reactor safety codes
 - Chinese experimental fast reactor went critical in July 2010 and achieved 40% power in July 2011
- Bilateral discussions on fast reactor collaborations with Russia on design of MBIR – replacement for BOR-60.



Fast and Thermal Spectrum System Innovations

- **Transformational Concepts**
 - Radical changes to conventional fast and thermal reactor systems are proposed
 - Definition, performance, and R&D identification for new ideas
- **Fast Reactor Educational and Training Materials**
 - Shrinking base of expert engineers and scientists
 - Develop communication tools (e.g., short course on fast reactor technology) with National Lab experts

Advanced Heat Transfer Systems

- **Advanced Compact Heat Exchanger**
 - Innovative compact heat exchangers are being sought and investigated for liquid (low pressure) to gas (high pressure) applications
 - Need ideas for increasing performance of heat transport systems

Safety System Technologies for Inherent Safety

- Reliance on prevention of accidents
- Advanced Self-actuated Shutdown Systems



Advanced Systems and Components

- Compact Fuel Handling Mechanisms
 - Work with National Lab partner to develop design concept for compact fuel handling systems
- Seismic Isolation Technology
 - Understanding implications of using seismic isolation technology for base isolation
 - Develop technologies for accommodating displacements in large diameter piping systems that span the seismic isolation gap
- Reliability, Maintainability, and Inspectability Technology
 - Develop systems for “looking through” non-transparent coolants
 - Develop technologies for repairing materials in-situ
 - Develop compact technologies for inspecting large vessels
- Systems for Corrosion control of molten-salt cooled systems

Backup

